Automatic stenosis detection and quantification in renal arteriography

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Visual assessment of the degree of renal artery stenosis on renal arteriography has a large inter- and intra-observer variability. This degree is usually estimated by the ratio between the most narrowed portion of the artery and the reference diameter. The latter is a priori unknown information and thus operator dependent. The objective of the present work was to test the performances of a computer system that was designed to analyze and quantify lesions on 2D renal arteriograms. The main hypothesis was to consider that the most frequent diameter computed along the artery was a good candidate to approximate the reference diameter. Forty nine patient images were collected from the EMMA randomized trial, a multicenter study comparing two treatment strategies in unilateral atheromatous renal artery stenosis of at least 60%. For each image, the degree of stenosis was evaluated by five independent experts and the mean value was used to represent the gold standard for the computer system. The system is based on a fuzzy automaton and performs a syntactic analysis of the arterial segment providing automatic and reproducible quantification of lesions. Both the radiologist caring for the patient and the system were compared to the gold standard. Compared to individual radiologists, the computer system gave a more precise estimation of percent stenosis and did not over or under estimate the severity of the lesion.

Keywords: renal arteriography, image quantification, image interpretation

INTRODUCTION

Despite the emergence of new techniques for the visualization and analysis of vascular structures (MRI, 3D reconstruction from X-ray CT, endo-vascular ultrasound, ...), arteriography remains the reference examination to quantify the severity of renal artery lesions. In the produced images, a pathological aspect is associated with an artery area where there is a significant deviation from the diameter of the healthy artery, usually called the *reference diameter*. In particular, a stenosis is associated with a significant narrowing of the artery and is quantified by some parameters such as the degree of stenosis [1]. The degree is usually estimated by the ratio between the most narrowed portion of the artery and the reference diameter. However, the visual assessment of this parameter is complicated and subject to a large inter- and intra- observer variability [2]. One difficulty comes from the inability to assess the real value of the healthy artery diameter which is *a priori* unknown information and thus operator dependent. Moreover, there is no universal medical framework for identifying and measuring it [3]. From these considerations, it has been argued that lesion quantification methods that standardize artery lesion description and automate lesion quantification are necessary to reduce the variability of stenosis degree estimation [3][4]. Computer vision systems have been designed to provide accurate and reproducible quantitative data from 2D angiograms, particularly in the field of coronary artery disease [4], [5], [6], [7]. In renal arteriography domain as well, some systems exist and are used in radiology departments. Over the last decade, research in the design of these systems has focused on the quality of the segmentation process that provides the outlines of the arteries [8]. After the segmentation step, a reference diameter is often calculated as the mean diameter along the artery and proposed to the radiologist that may either validate it or change it [7]. On one hand, it is obvious that the mean diameter is not satisfactory. Indeed, if there is an elongated and narrow stenosis with no post-stenotic dilatation, the mean diameter can be drastically smaller than the true reference diameter value and the degree of stenosis will be underestimated by the system. On the other hand, if the radiologist changes the value, he/she introduces a degree of variability in the final result. Within this context, our research hypothesis was to consider that the most frequent diameter computed along the artery was a good candidate to approximate the true reference value. In this paper, we present a study testing this hypothesis. We used a computer system that describes and quantifies renal artery lesions [9] and which is based on a fuzzy syntactic analysis procedure [10]. Performances of the system were tested on 49 arteriographies that came from a French randomized trial comparing two treatment strategies in unilateral atheromatous renal artery stenosis (EMMA trial). Using a gold standard defined within this trial, we show that the automatic quantification system performs well as compared to the individual radiologist who cared for the patient.

OBJECTIVES

The long term objective is to end up with an automatic quantification procedure that will be reproducible and reliable enough to fit in the daily clinical practice. In the first part of our research, we were interested in the evaluation of the procedure from a computer point of view. The originality of the system is to rely on an automatic computation of the reference diameter, the hypothesis being that the most frequent diameter along the artery is the reference diameter. Under this hypothesis the specific objectives of the present work were to answer the two following questions: while analyzing the artery, does the program find the relevant lesions? Does the program provide a good measurement of the degree of stenosis?

In order to answer these questions, we considered a set of images that have been selected between 1990 and 1995 in the context of a French multicenter controlled trial. This validation set had two advantages:

- images were collected independently of the development of the system,
- patients of the trial were recruited in several centers in France with a unilateral renal artery stenosis >60% as the unique morphological criterion. Therefore, they represent the usual picture of the disease in university hospital radiology departments.

MATERIALS AND METHODS

The testing material

The primary aim of the randomized EMMA trial was to compare the efficacy on hypertension control of two treatment strategies, antihypertensive drugs alone vs. antihypertensive drugs plus angioplasty. Forty nine patients images were collected from this trial.

Using digital angiography technique, images given by blood vessels were first enhanced by injection of a radio-opaque contrast substance via a catheter, and further improved by subtraction of a pre-contrast from a post-contrast image. The Investigator (I) in charge of the patient quantified visually the degree of stenosis of the renal artery. As regards the gold standard, it was determined by a panel of 5 expert radiologists according to the following procedure. They first selected one image per patient, that allowed the best visualization and characterization of the stenosis. They then used a ruler to measure the reference diameter (Dref) and the minimum diameter (Dmin) in each image, independently of each other. From these measurements, the value of the degree of stenosis was given by [4]:

Dg = (1 - Dmin/Dref) *100%.

Finally, the result of the measurements, called consensus (the gold standard), was the mean of the measurements recorded by the five observers.

Digitalization and image segmentation

Classical image processing techniques were used to perform digitalization and segmentation. Images were numerized into 512 by 512 pixels and 256 grey level via Duo scan Agfa scanner. A semi-automatic segmentation procedure was further applied using the NIH 1.60 public domain image processing tool. The result of the segmentation was then validated by the radiologist (figure1).

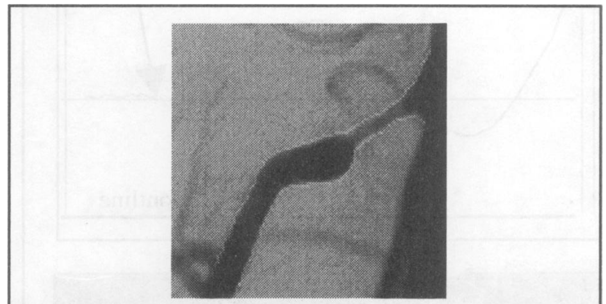


Figure1: The segmentation step

The automatic quantification procedure

After the segmentation step, the different steps involved in the extraction of a quantified description of the renal artery lesion are represented in figure 2.

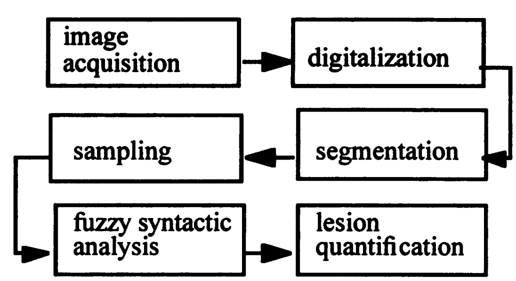


Figure2: The different steps of the procedure from the acquisition to the quantification

Sampling the artery

The sampling procedure takes the artery outlines as input and generates the diameter function as output. A method similar to the "adaptive tracking" technique is used [9]. The method consists in identifying the central line of the artery. The search of the mean direction of the central line is updated based on the local orientation of points on the boundaries. Each diameter is obtained by joining boundaries points orthogonally to the central line direction. Finally, a diameter profile is defined as the graphical representation of the diameter function (figure 3). The most frequent diameter is extracted from the diameter profile in the following way:

- the diameter profile is divided in twenty equal segments,
- an histogram is built according to this twenty segments and each diameter value is ranged in one segment,
- the high of the histogram yields the segment corresponding to the most frequent range of diameter values,
- the reference diameter is taken in the middle of the selected segment.

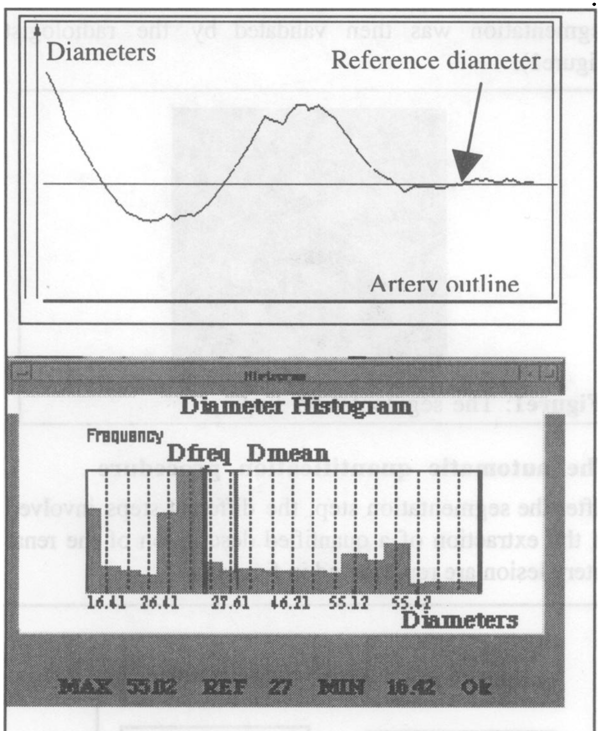


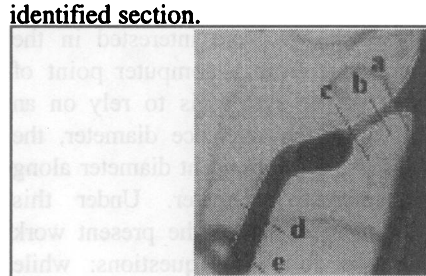
Figure3: Determination of the reference diameter

In figure 4, the depicted area between the frontiers d and e corresponds to the area where the reference diameter is computed by the system.

Fuzzy syntactic analyzer and quantification

Using the most frequent diameter as the reference diameter, the outlines are syntactically analyzed to extract a structural description in terms of the sequence of lesions observed along the artery. The syntactic analysis is realized by a fuzzy automaton [10] that detects areas that have a diameter globally larger than the reference diameter (dilatation) and areas that have a diameter globally smaller than the reference diameter (stenosis). The remaining areas are labeled as normal. Each lesion is quantified by the set of parameters that characterizes it. For instance, the degree of stenosis, its length, its position, its aspect and its character are the five parameters that characterize a stenosis [9].

In our study we were interested at first in the degree of stenosis. The percentage of stenosis was estimated by the quantity: $Dg = (1 - Dmin/Dref)*100\%$ where Dref was the most frequent diameter (between d and e in figure 4) and Dmin was the local minimum diameter inside the stenosis area (b in figure 4). In the previous example, the final result of the automatic quantification procedure showed a very short first dilatation corresponding to the ostium; a 61% stenosis located between the lines a and c; a post-stenotic dilatation. The reference diameter is taken within the last normal identified section.



Dilatation	(length 11% of total length)
	(aspect non-centered)
Stenosis	(length 27% of total length)
	(degree 61%)
	(aspect centered)
	(character irregular)
	(position troncular)
Dilatation	(length 28%)
	(aspect centered)

Figure4: Results of the quantification procedure

In order to validate the system results in term of degree of stenosis, a quantitative evaluation was made by comparing the gold standard to the results of the system.

RESULTS AND DISCUSSION

The automatic quantification procedure was developed in the C++ programming language on a Macintosh platform. The image database of 49 arteriograms was used to test the automatic detection and quantification procedure. In the presentation of the results, we only considered the degree of stenosis in the global symbolic description. According to our objectives, we have defined two criteria for the interpretation of the results:

- First, the system found the stenosis along the artery. It means that the most frequent diameter allows to detect correctly the pathological aspects of the renal artery. There is one exception that is discussed later.
- Second, the system provided a correct, reproducible and reliable estimation of the degree of stenosis. The interpretation should be restricted to the context of the selected 49 images. Indeed, only arteries with single atheromatous stenosis were included in the image database.

Both the Investigator (I) caring for the patient and the computer System (S) were compared to the gold standard (G). The mean differences S-G and I-G were -0.34 ± 5.26%, and +2.51 ± 10.14%, respectively, none of these differences differing statistically from zero using a 2-tailed paired t-test. This means that neither the investigator nor the computer system systematically over- or under-estimated the degree of stenosis, by comparison to the gold standard. Another way of comparing 2 methods of measurement is to plot the difference against the average of the measurements by the 2 methods, as proposed by Bland and Altman [11]. The computer system gives a precise and unbiased estimation of percent stenosis (Figure 5).

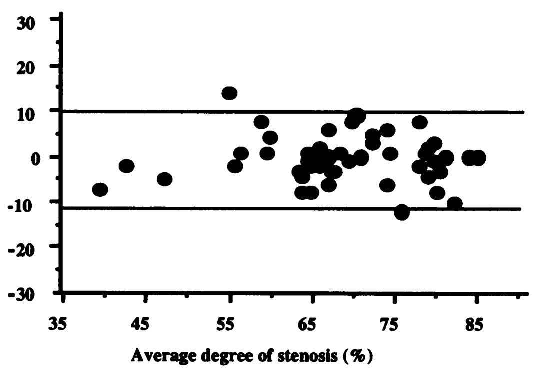


Figure5: Comparison of the computer system to the gold standard with 95% limit of agreement (horizontal lines)

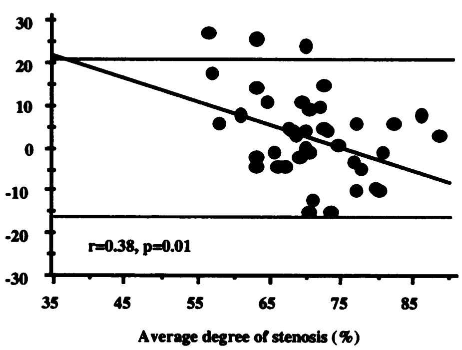


Figure6: Comparison of the investigator to the gold standard with 95% limit of agreement (horizontal lines) and regression line.

By contrast (Figure 6), limits of agreement are wider when the comparison concerns the investigator and the difference decreases with the magnitude of the measurement suggesting greater variability of the investigator.

These results suggest that choosing the most frequent diameter as the reference diameter was appropriate for assessing the degree of stenosis.

Most of the time, the reference diameter was correctly positioned by the computer system. Nevertheless, the system needs some improvements for two aspects:

- In two cases, the system did not detect the stenosis correctly (figure 7) or did not detect the stenosis at all. The mistake was due to the number of segments used to build the histogram. Indeed, the number of segments should be a parameter depending on the sampling of the artery and not a fixed value. In this case, the reference diameter was not positioned correctly by the system.
- The final degree of stenosis is still dependent on the segmentation procedure. The segmentation validation step should be more controlled.

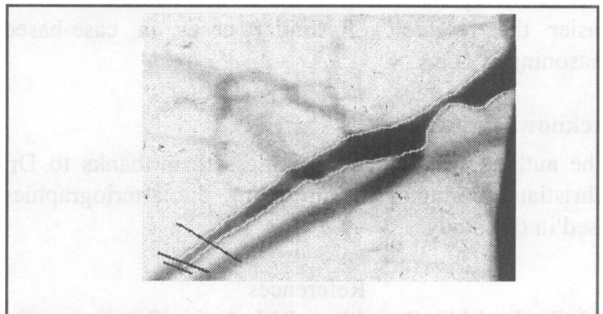


Figure 7: The that was not detected by the system.

From the obtained symbolic descriptions, it appeared that the ostium of most renal arteries has a conic aspect, i.e. the diameter of artery is wider at the origin than some millimeters after the origin. This point could be easily solved using a conic model to determine the reference diameter at the ostium and a cylinder model to determine the reference diameter in the rest of the artery.

CONCLUSION

In this paper, we described the evaluation of a computer-based automatic quantification system in the domain of renal arteriographies. This evaluation was performed on the arteriograms of 49 patients having an unilateral atheromatous renal artery stenosis.

The quantification procedure used in the present work is based on a fuzzy automaton. It performs a syntactic analysis of the arterial segment from a diameter profile and provides a structural description as a list of segments representing the different normal and abnormal aspects of the artery. Each segment is quantified by the set of attributes that characterizes it.

The objectives of this paper were to show that the computer-based system provides results close to the gold standard, and that the reference diameter taken as the most frequent diameter was a good reference for assessing the diameter percent stenosis. Our results also demonstrate that the computer based system has an acceptable accuracy in the quantification of the stenosis degree comparing favorably with that of a single radiologist in charge of a patient.

The short term perspectives of our work concern the improvement of the automatic quantification procedure at the level of the segmentation step. Some preliminary work has been done to develop a segmentation procedure that 1) identifies automatically in the image the different regions of interest and 2) finds automatically the boundaries of these identified structures [12].

The long-term perspective are the standardization of automatic detection and the quantification of renal lesions as a step towards the automatic reporting of results and archiving in a database. Automatic interpretation could be used for increasing the speed of image retrieval, and performing robust statistical studies. The fuzzy representation of the results could also make easier the research of similar cases in case-based reasoning systems.

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